CALIFORNIA DIVISION OF MINES AND GEOLOGY
FAULT EVALUATION REPORT FER-189

RECENTLY ACTIVE TRACES OF THE BLACKWATER, HARPER, LOCKHART AND RELATED FAULTS NEAR BARSTOW, SAN BERNARDINO COUNTY

by

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INTRODUCTION

Potentially active faults in western San Bernardino County that are evaluated in this Fault Evaluation Report (FER) include strands of the Lockhart, Harper and Blackwater fault zones and related faults (Figure 1). The northwestern Barstow study area is located in parts of the Barstow, Boron NE, Hinkley, Nebo, Saddleback Mountain and Twelve Gauge Lake 7 1/2-minute quadrangles and the Fremont Peak and Opal Mountain 15-minute quadrangles (Figure 1). These faults are evaluated as part of a statewide effort to evaluate faults for recency of activity. Those faults determined to be sufficiently active and well-defined are zoned by the State Geologist as directed by the Alquist-Priolo Special Studies Zones Act of 1972 (Hart, 1985).

SUMMARY OF AVAILABLE DATA

The northwest Barstow area, located in the Mojave Desert geomorphic province, is characterized by generally northwest-trending, right-lateral strike-slip and oblique-slip faults (Dibblee, 1967; Garfunkel, 1974; Dokka, 1983; Dibblee, 1985). The study area lies in the northern part of the central Mojave Desert as designated by Bull (1978). Bull considers the central Mojave Desert to be tectonically active, although he stated that the relative tectonic activity decreases to the north of Barstow (Bull, 1978, p. 73).

Topography in the study area ranges from flat playa surfaces and bajadas, to eroded hills of moderate to rugged relief. Development in the study area ranges from moderate in the area around Barstow to low in outlying parts of the study area. Rock types in the study area consist of pre-Mesozoic metamorphic rocks, abundant Tertiary sedimentary and volcanic rocks, Pleistocene and Holocene alluvium, eolian, and playa deposits (Dibblee, 1958, 1960a, 1960b, 1967, 1968, 1970; Bortugno and Spittler, 1986; Hsu and Wagner, in preparation).

LOCKHART FAULT ZONE

The Lockhart fault zone consists of the Lockhart, South Lockhart and North Lockhart faults (Figures 1, 2a, 2b). Dibblee (1985) stated that the Lockhart fault zone is probably genetically related to the northwestern part of the

Helendale fault. Dibblee reported that both of these fault zones offset late Quaternary alluvium, but that Holocene alluvium is not offset. Jennings (1975) depicted the Lockhart fault zone as a probable northwest continuation of the Lenwood fault. Wesnousky (1986) reported a late Cenozoic slip-rate of 0.9 to 2.5 mm/yr along the Lockhart fault zone, based on data published by Garfunkel (1974). It is not known what relationship, if any, exists between this long term slip-rate and the late-Quaternary slip-rate along the Lockhart fault zone.

Lockhart Fault

The Lockhart fault is a 40 km-long, northwest-trending high-angle fault mapped by Dibblee (1958, 1968) and Page and Moyle (1960) (Figure 2a). The magnitude of displacement along the Lockhart fault is not known, but Dibblee (1968) stated that the fault is right-lateral strike-slip with a component of down-to-the-northeast vertical displacement. The Lockhart fault offsets Quaternary alluvium and juxtaposes Holocene alluvium against older (Pleistocene) alluvium at localities 1-4 (Figure 2a) (Dibblee, 1958, 1968). Dibblee (1968) did not map the Lockhart fault southeast of locality 5, but Page and Moyle (1960) extended the Lockhart fault about 25 km to the southeast as an approximately located fault in Quaternary alluvium (Figures 2a, 2b).

The existence of this southeastern projection of the Lockhart fault is proabably based on water well data. An apparent groundwater barrier in the older alluvium of Page and Moyle (1960) is indicated by a difference in water levels of 22.18 feet (6.7 m) between well D2 and C2 at locality 6 (Figure 2b). However, only one data point exists on the northeast side of the fault at this location. Several wells in older alluvium within 1 km of the southwest side of the fault have water levels that range from 48 feet (29L1) to 64 feet (29P1) (Figure 2b). The non-uniformity of depths to ground water indicates that there may be rapid facies changes within the older alluvium, more than one aquifer, or folding or faulting of a single aquifer along a broad zone of faulting approximately 1 km wide.

Dibblee (1958) mapped an inferred branch fault along the northern end of the Lockhart fault as offsetting Holocene alluvium (locality 7, Figure 2a). This fault segment is also associated with small playas, possibly suggesting recent ground deformation. However, Dibblee (1985) concluded that the Lockhart fault is not Holocene active, but was active about 200ka. Dibblee (1985) stated that the Lockhart fault shows little topographic expression, but is prominent on air photos.

North Lockhart Fault

The North Lockhart fault is a 6.4 km long, northwest-trending fault mapped by Dibblee (1968) and Page and Moyle (1960) (Figure 2a). The fault has a right-lateral oblique sense of displacement, based on a "small" right-lateral offset of pre-Mesozoic Waterman Gneisic Complex and a down-to-the-north vertical component of displacement (Dibblee, 1968). The North Lockhart fault juxtaposes Quaternary alluvium against Holocene alluvium at locality 8 (Figure 2a), but farther southeast the fault is concealed by Holocene alluvium (Dibblee, 1968).

South Lockhart Fault

The South Lockhart fault is a 27 km-long, north to northwest-trending fault mapped by Dibblee (1958, 1960b, 1968) and Page and Moyle (1960) (Figure 2a). Page and Moyle (1960) considered the South Lockhart fault to be the northern most extension of the Helendale fault, but in this report the fault will be considered to be a segment of the Lockhart fault zone. The South Lockhart fault is probably characterized by right-lateral strike-slip displacement; the sense of apparent vertical displacement varies along the fault from south side down at the southern end of the fault to north side down along the central and northern segments of the fault (Dibblee, 1968). The magnitude of displacement along the South Lockhart fault is not known.

The South Lockhart fault offsets Quaternary alluvium and locally juxtaposes Quaternary alluvium against Holocene alluvium (localities 9, 10, Figure 2a) (Dibblee, 1960b; Page and Moyle, 1960). Dibblee (1960b) inferred that Holocene alluvium is offset just south of locality 9, but generally the fault is concealed by Holocene alluvium (Figure 2a).

HARPER FAULT ZONE

The Harper fault zone, first named by Hewett (1954), is a significant northwest-trending zone of discontinuous, parallel, high-angle faults along the southwest edge of the Gravel Hills and Black Mountain (Figures 1, 2b). Dibblee (1968) divided the Harper fault zone into four segments: the Cuddeback, Gravel Hills, Harper Valley, and Black Mountain faults (Figure 2b). In addition, Bortugno and Spittler (1986) termed the southern extension of the Black Mountain fault in the Barstow 15-minute quadrangle the Harper Lake fault (Figure 2b). The sense of displacement along the Harper fault zone is right-lateral strike-slip with a generally up-to-the-northeast component of vertical displacement (Dibblee, 1968). Bird and Rosenstock (1984) and Wesnowsky (1986) reported a minimum slip-rate of 0.2 mm/yr along the Harper fault zone.

Cuddeback Fault

The Cuddeback fault, located at the northern end of the study area, is a right-lateral strike-slip fault mapped by Dibblee (1968) (Figure 2b). The Cuddeback fault extends northwest into the Cuddeback Lake 15-minute quadrangle, but this northwest extension will not be evaluated due to time constraints. The Cuddeback fault offsets Tertiary Barstow Formation and locally juxtaposes the Barstow Formation against Holocene alluvium (Figure 2b). The magnitude of displacement is not known.

Gravel Hills Fault

The Gravel Hills fault is a 16 km-long, high-angle fault mapped by Dibblee (1968) and Moyle (1970) (Figure 2b). The sense of offset along the Gravel Hills fault is right-lateral oblique with a significant component of up-to-northeast vertical displacement (Dibblee, 1968). The magnitude of displacement is not well constrained, but Dibblee (1968) suggested that the axis of the Gravel Hills syncline may be offset as much as 0.8 km right-laterally (locality 11, Figure 2b). Dibblee (1968) mapped Holocene alluvium as offset along the northern Gravel Hills fault at locality 12 (Figure 2b), and mapped Holocene alluvium juxtaposed against Tertiary Barstow Formation southeast of locality 12. Moyle (1970) interpreted the deposits offset at locality 12 to be Barstow Formation rather than Holocene alluvium. The southeastern end of the Gravel Hills fault is concealed by Pleistocene alluvium (locality 13, Figure 2b).

Harper Valley Fault

The Harper Valley fault is a 12 km-long, northwest-trending fault mapped by Dibblee (1968) and Moyle (1970) (Figure 2b). The style of displacement along the Harper Valley fault is predominantly up-to-northeast vertical, according to Dibblee (1968). The magnitude of displacement is not known for the Harper Valley fault. Both Dibblee (1968) and Moyle (1970) mapped Holocene alluvium as offset along the Harper Valley fault at locality 14 (Figure 2b).

Black Mountain Fault

The Black Mountain fault mapped by Dibblee (1968) and Moyle (1970) is a complex, northwest-trending zone of distributive high-angle faults (Figure 2b). Right-lateral strike-slip displacement of about 0.8 km is indicated by Dibblee (1968), based on displacement of the Black Canyon anticline. Total vertical displacement along the Black Mountain fault may be as much as 600 meters, according to Dibblee (1968).

The Black Mountain fault offsets the Black Mountain Basalt, a late Tertiary basalt radiometrically dated at 2.55 $\pm$ 0.58 m.y. (Burke and others, 1982). The Black Mountain Basalt (Qb) was previously mapped by Dibblee as Pleistocene in age. In addition to faulting, the surface of the basalt is deformed by folding that is consistent with right-lateral strike-slip deformation. Holocene alluvium is juxtaposed against the basalt at locality 15, but southeast of this locality the fault is concealed by Holocene alluvium (Figure 2b). An old shoreline of Harper Lake, presumably of latest Pleistocene to early Holocene age, is not offset by the Black Mountain fault (locality 16, Figure 2b).

Harper Lake Fault

The Harper Lake fault is probably the southeastern continuation of the Black Mountain fault of Dibblee (1968) (Figure 2b). The Harper Lake fault, mapped by Dibblee (1960a, 1970) and Page and Moyle (1960), is a right-lateral oblique-slip fault. The magnitude of displacement is not known. Dibblee (1960a, 1970) mapped Holocene alluvium juxtaposed aginst bedrock (e.g. locality 17, Figure 2b) and the fault offsets Quaternary alluvium at locality 18 (Figure 2b). Page and Moyle (1960) mapped Holocene alluvium as offset along a branch of the Harper Lake fault at locality 19 (Figure 2b). Dibblee (1970) did not map the Harper Lake fault southeast of the Mojave River (Figure 2b).

BLACKWATER FAULT ZONE

The Blackwater fault zone is a major northwest-trending right-lateral strike-slip fault (Figures 1, 2b). The Blackwater fault zone extends northwest of the study area and has been mapped by Smith (1964). This northern segment of the Blackwater fault will not be evaluated due to time constraints.

The Blackwater fault offsets the Pliocene Black Mountain Basalt about 1.6 km in a right-lateral sense, according to Dibblee (1968). This displacement allows a very approximate slip-rate of 0.6 mm/yr to be calculated for the Blackwater fault. Bird and Rosenstock (1984) reported a slip-rate of $\underline{+}$ 0.41 mm/yr along the Blackwater fault and Wesnousky (1986) reported a slip-rate of 0.4 mm/yr. Arching and folding of the Black Mountain Basalt, in addition to offsets of Mesozoic quartz monzonite, support the predominatly right-lateral strike-slip sense of offset along the Blackwater fault (Dibblee, 1968). The fault locally juxtaposes Holocene alluvium against basalt (locality 20, Figure 2b), but generally the fault is concealed by Holocene alluvium.

Southeast of locality 20 the Blackwater fault splays into several short, discontinuous northwest-trending faults, including the Coolgardie, Fossil Canyon and Coon Canyon faults (Dibblee, 1968, Figure 2b). The Fossil Canyon fault locally offsets Quaternary alluvium (locality 21, Figure 2b), although elsewhere the fault is concealed by Quaternary alluvium (locality 22, Figure 2b). The Coolgardie fault is located entirely within bedrock and the Coon Canyon fault locally juxtaposes Quaternary alluvium against bedrock (Figure 2b).

Bull (1978) considered the Blackwater fault to range from a class 2 (moderate to slightly active) to a class 3 (tectonically inactive) terrain. The class 2 terrain, located in the Black Mountain Basalt, is explained by Bull as occuring only because of the highly resistant nature of the basalt. Bull concluded that there has been minimal tectonism since early Pleistocene time.

MT. GENERAL FAULT

The Mt. General fault, informally named in this report, is a 19 km-long, northwest-trending fault mapped by Dibblee (1960a) and Page and Moyle (1960) (Figure 2b). The style of displacement along the Mt. General fault is up-on-northeast vertical as mapped by Dibblee (1960a), but the linearity of the fault trace suggests a significant component of strike-slip displacement. The magnitude of displacement along the Mt. General fault is not known.

The Mt. General fault offsets Quaternary fanglomerate deposits south of the Mojave River and locally juxtaposes bedrock against Holocene alluvium (localities 23, 24, Figure 2b). However, most of the Mt. General fault mapped by Dibblee (1960a) is concealed by Holocene alluvium (Figure 2b). Page and Moyle (1960) mapped Holocene alluvium juxtaposed against bedrock near locality 23 and at locality 25 (Figure 2b). Water-well data suggests a ground water barrier at locality 26 where an approximately 2 meter difference in ground water levels between wells M1 and M3 was reported by Page and Moye (1960 (Figure 2b).

INTERPRETATION OF AERIAL PHOTOGRAPHS AND FIELD OBSERVATIONS

Aerial photographic interpretation by this writer of faults in the northwest Barstow study area was accomplished using U.S. Department of Agriculture (AXL, 1952, scale 1:20,000) and U.S. Bureau of Land Management (CAHD-77, 1978, scale 1:30,000) air photos.

Approximately 4-1/2 days were spent in the study area in late March 1987 by this writer. Selected fault segments were field checked and subtle features not observable on the aerial photographs were mapped in the field. Results of aerial photographic interpretation and field observations by this writer are summarized on Figures 3a-3c.

LOCKHART FAULT ZONE

Lockhart Fault

The Lockhart fault is a moderately to poorly defined fault as mapped by Dibblee (1958, 1968), although the fault is locally moderately well-defined (Figures 2a, 2b, 3a, 3b). The southernmost segment of the fault mapped by Page and Moyle (1960) is poorly defined and was not verified in the older alluvium by this writer (Figure 2a, 2b).

The best-defined segment of the Lockhart fault is delineated by a moderately well-defined, northeast-facing scarp in what Dibblee (1968) mapped as Pleistocene alluvium (locality 27, Figures 2a, 3b). The Pleistocene alluvium at this location is probably older than 100 ka and possibly older than 500 ka, based on multiple K (pedogenic carbonate) horizons, degree of induration and dissection of the alluvium. This segment of the fault is characterized by a significant component of up-on-the-southwest vertical displacement; geomorphic evidence of right-lateral strike-slip displacement was not observed (Figure 3b). To the northwest of locality 27, geomorphic features such as linear ridges in crystalline bedrock and right-laterally deflected drainages indicate right-slip faulting (Figure 3b). These geomorphic features are permissive of Holocene strike-slip faulting, but may be enhanced by differential erosion. This southeastern segment of the Lockhart fault is probably characterized by a late Quaternary slip-rate of less than 1 mm/yr.

Geomorphic evidence of Quaternary activity was observed along the Lockhart fault northwest to sec. 19, T32S, R41E and the Lockhart fault mapped by Dibblee (1958, 1968) was verified with respect to general location (Figures 2a, 3a, 3b). However, the fault is generally only moderately to poorly defined in detail and most geomorphic features are probably erosional (Figures 2a, 3a, 3b). Several closed depressions are located close to the fault but do not appear to be related to recent faulting (locality 28, Figure 3a). Scarps in older alluvium are dissected and may be erosional features. Thus, Quaternary deformation has occurred along this segment of the Lockhart fault, but geomorphic evidence of Holocene faulting is lacking.

Several north-trending fault segments characterize the northern part of the Lockhart fault (Figure 3a). These fault segments are delineated by very subtle scarps and tonal lineaments in late Pleistocene alluvium, and playas that may be large closed depressions (Figures 3a). A representative scarp profile at locality 29 (Figure 3a) does not support Holocene displacement. The fault Dibblee (1958) inferred to offset Holocene alluvium at locality 7 (Figure 2a) was not verified by this writer, based on air photo interpretation.

North Lockhart Fault

The North Lockhart fault mapped by Dibblee (1968) is moderately defined locally and was only partly verified by this writer (Figures 2a, 3b). A north-facing scarp in Pleistocene alluvium mapped by Dibblee (1968) near locality 8 (Figures 2a, 3b) was verified. The scarp is in alluvium that is probably equivalent in age to the deposits offset along the Lockhart fault near locality 27 (Figure 3b). The scarp is highly dissected and locally enhanced by lateral stream erosion. Geomorphic evidence of Holocene faulting was not observed by this writer, based on air photo interpretation and field checking (Figures 2a, 3b).

South Lockhart Fault

The South Lockhart fault mapped by Dibblee (1958, 1960b, 1968) was locally verified by this writer (Figures 2a, 3b). The fault is poorly defined at its northern end and is not characterized by geomorphic features indicating recent faulting (Figure 2a). The central segment from locality 30 southeast to locality 31 (Figure 3b) is well-defined and is delineated by geomorphic features indicating Holocene faulting, such as scarps in latest Pleistocene to Holocene alluvium, trough and graben in alluvium, right-laterally deflected drainages, and ponded alluvium (Figure 3b).

Recent activity is discontinuous and distributive along the South Lockhart fault south of locality 31 (Figure 3b). Locally, well-defined scarps in Pleistocene alluvium are associated with tonal lineaments, right-laterally deflected drainages, and a closed depression (Figure 3b). Additional fault segments are not well-defined and lack geomorphic evidence of latest Pleistocene and Holocene displacement (Figure 3b).

HARPER FAULT ZONE

Cuddeback Fault

The Cuddeback fault mapped by Dibblee (1968) in the study area is generally not well-defined and was not verified as a Holocene active fault (Figures 2b, 3b). The geomorphic features delineating the Cuddeback fault in Tertiary Barstow Formation are more characteristic of differential erosion.

Gravel Hills Fault

The northwest half of the Gravel Hills fault is moderately well defined to well-defined and is delineated by geomorphic features indicating Holocene faulting (Figure 3b). A well-defined, south-facing scarp is very fresh and is associated with a closed depression (locality 12, Figures 2b, 3b). Dibblee (1968) mapped the fault at this location as offsetting Holocene alluvium, but Moyle (1970) mapped the deposit as Tertiary bedrock (Figure 2b). The Barstow Formation near this location consists of coarse indurated fanglomerate with boulder-sized clasts predominantly of granitic composition. The faulted deposit at locality 12 is not well-exposed, but the clasts are generally much smaller than clasts exposed in the Barstow Formation, and the clasts at locality 12 have a much higher volcanic population. Thick, abraded carbonate rinds on some clasts excavated on top of the scarp suggest that the deposit is alluvium derived from the Barstow Formation.

Southeast of this scarp the Gravel Hills fault is delineated by moderately dissected southwest-facing scarps in Barstow Formation and, locally, subdued scarps in late Pleistocene alluvium (locality 32, Figure 3b) Southeast of this location the Gravel Hills fault is delineated by a moderate to poorly-defined, highly dissected scarp in Barstow Formation (Figure 3b). The Gravel Hills fault cannot be followed southeast of locality 33 (Figure 3b).

Harper Valley Fault

The Harper Valley fault mapped by Dibblee (1968) is locally well-defined and has geomorphic evidence of latest Pleistocene to Holocene displacement. A subtle northeast-facing scarp in latest Pleistocene alluvium (Dibblee mapped a down-to-southwest fault) is associated with linear tonal contrasts in Holocene alluvium, ponded alluvium, and a trough in latest Pleistocene alluvium (locality 34, Figure 3b). The eastern fault segment mapped by Dibblee is delineated by a moderately defined northeast-facing scarp that may be an erosional feature (Figure 3b). To the southeast, the fault vertically offsets Pliocene Black Mountain Basalt (up-on-northeast), but the fault is concealed by Holocene alluvium and cannot be followed farther southeast (Figures 2b, 3b).

Black Mountain Fault

The Black Mountain fault is a complex, distributive zone of faults that are generally well-defined. Faults mapped by Dibblee (1968) were verified, though differences in detail exist (Figures 2b, 3b). Well-defined geomorphic features in Pliocene Black Mountain Basalt, such as linear ridges and troughs, right-laterally deflected and beheaded drainages, closed depressions, ponded alluvium, and sidehill benches, strongly indicate latest Pleistocene to Holocene right-lateral strike-slip displacement (localities 35 and 36, Figure 3b). Dibblee (1968) and Bull (1978) pointed out that the Black Mountain Basalt is very resistant and geomorphic features are preserved over a greater period of time. However, latest Pleistocene to Holocene faulting along the Black Mountain fault southeast of the Black Mountain Basalt is indicated by subtle scarps in late Pleistocene and possibly Holocene alluvium, a linear trough in alluvium, tonal lineaments in Holocene, and right-laterally defected drainages (locality 37, Figure 3b). These geomorphic features along the southern Black Mountain fault are moderately well-defined.

Harper Lake Fault

The Harper Lake fault is a moderately to poorly defined fault that offsets late Pleistocene alluvium at locality 38 (Figure 3c). Southwest facing scarps (breaks-in-slope) in late Pleistocene to Holocene alluvial fans and right-laterally deflected drainages suggest latest Pleistocene and possible Holocene right-lateral strike-slip displacement (localities 38, 39, Figure 3c). However, these features are generally poorly defined and are not associated with additional geomorphic evidence of recent strike-slip faulting. Southeast of locality 39, geomorphic features in bedrock, such as right-laterally deflected drainages, saddles, benches, and linear ridges, are not well-defined and are probably due to differential erosion (Figure 3c).

BLACKWATER FAULT ZONE

Blackwater Fault

The Blackwater fault in the study area is a moderately to well-defined, right-lateral strike-slip fault zone (Figure 3b). Abundant geomorphic evidence of latest Pleistocene to Holocene right-lateral strike-slip faulting, such as scarps, linear ridges, closed depressions, sidehill benches, right-laterally deflected drainages, and ponded alluvium, was observed within the Pliocene Black Mountain Basalt (localities 40, 41, Figure 3b). The ponded alluvium observed at locality 40 has a weakly developed B soil horizon, indicating latest Pleistocene to early Holocene age of the alluvial surface (Figure 3b). The geomorphic features along the Blackwater fault within the Black Mountain Basalt are not highly eroded, as reported by Bull (1978), but are relatively fresh.

Northwest of sec. 31, T31S, R45E, the Blackwater fault is delineated by linear ridges, dissected scarps and right-laterally deflected ridges in bedrock (Figure 3b). These geomorphic features are only moderately defined and may be the result of differential erosion. However, a closed depression and vague tonal lineament in Holocene (?) alluvium suggest recent right-lateral faulting (locality 42, Figure 3b).

Faults Southeast of Blackwater Fault

The Blackwater fault zone southeast of Murphy's Well is poorly to moderately defined and is delineated by a broad northwest-trending zone of distributive faults (Figure 3b). The moderately defined faults include the Coolgardie and Fossil Canyon faults (Figures 2b, 3b). The Coolgardie fault (not plotted on Figure 3b) is located entirely within Mesozoic granitic bedrock and is delineated by geomorphic features, such as linear ridges, that are characteristic of differential erosion along a fault (Figure 2b). The Fossil Canyon fault locally offsets Pleistocene alluvium and is delineated by a northeast-facing scarp, linear trough, and tonal lineaments (Figure 3b).

The Fossil Canyon fault is moderately well-defined. The Coon Canyon fault of Dibblee (1968) was not verified as a recently active fault (Figure 2b).

MT. GENERAL FAULT

The Mt. General fault is generally a moderately well-defined fault and was mostly verified as mapped by Dibblee (1960a), although significant differences in detail exist (Figures 2b, 3c). The Mt. General fault is delineated by geomorphic features such as a linear ridge in latest Pleistocene alluvium, right-laterally deflected drainages, scarps in latest Pleistocene to Holocene alluvial fans, and tonal lineaments in Holocene alluvium (localities 43-45, Figure 3c). Although the southwest-facing scarps in the alluvial fan at locality 45 could be a wave-cut shoreline of ancient Harper Lake, the scarp aligns with additional geomorphic features delineating the Mt. General fault (Figure 3c). The Mt. General fault is less well-defined just north of the Mojave River and is delineated by geomorphic features in foliated metamorphic bedrock (linear ridges, benches, trough) more characteristic of differential erosion, although tonal lineaments in Holocene alluvium associated with these bedrock features suggest recent faulting (Figure 3c). The Mt. General fault mapped by Dibblee (1968) and Page and Moyle (1960) was not verified southeast of the Mojave River (Figure 2b).

The Mt. General fault is generally concealed by very young alluvial fans along the southwest flank of Mt. General, although tonal lineaments and a notch in a Pleistocene alluvial fan indicate the location of the Mt. General fault (Figure 3c). Vague tonal lineaments in late Pleistocene to Holocene alluvium suggest the location of the Mt. General fault northwest of Mt. General (Figure 3c). The apparent ground water barrier in alluvium reported by Page and Moyle (1960) at locality 26 is not delineated by geomorphic evidence of recent faulting or tonal lineaments in alluvium (Figure 2b). There doesn't seem to be any correlation between ground water levels reported in Page and Moyle (1960) and tonal lineaments mapped by this writer (Figure 2b, 3c).

FAULT ALONG WEST SIDE OF HARPER LAKE

The western shoreline of Harper Lake is unusually linear and recent faulting is indicated by an alignment of tonal lineaments in Holocene alluvium, a subtle east-facing scarp in Holocene alluvium and a west-facing scarp in late Pleistocene alluvium (localities 46, 47, Figure 3b). The inferred fault has not previously been mapped.

Water well information is not complete for this area and does not indicate whether or not the inferred fault is a ground water barrier (Figure 3b). The southeastern end of this inferred fault is very subtle in the field and is located in late Pleistocene alluvium (locality 48, Figure 3 b). The scarps in alluvium conceivably could be due to shoreline processes of Harper Lake, but the alignment with moderately well-defined tonal lineaments in late

Pleistocene and Holocene alluvium for over 11 km indicates that recent faulting is a reasonable interpretation of these features.

SEISMICITY

Seismicity in the northwestern Barstow study area is depicted in Figure 4. A and B quality epicenter locations by California Institute of Technology are for the period 1932 to 1985 (CIT, 1985).

There are no well-defined zones of microseismicity associated with any of the faults in the study area (Figure 4). Several epicenters are located between the Harper Lake fault and the Calico fault, a cluster of epicenters is located on the Lockhart fault (possible quarry blasts(?)), and there are a few scattered epicenters located along the Blackwater fault (Figure 4). A possible linear zone of seismicity extends southeast from the Black Mountain fault (Figure 4).

CONCLUSIONS

LOCKHART FAULT ZONE

The Lockhart fault zone is a generally northwest-trending zone of right-lateral strike-slip and oblique-slip faults that offset Pleistocene alluvium (Dibblee, 1958, 1960b, 1968; Page and Moyle, 1960) (Figures 2a, 2b, 3a, 3b). The Lockhart fault zone consists of the Lockhart, North Lockhart, and South Lockhart faults.

The Lockhart fault mapped by Dibblee (1958, 1968) was only locally verified by this writer (Figure 2a). The Lockhart fault is moderately well-defined near locality 27 (Figure 3b), where is offsets Pleistocene fanglomerate of mid to late Pleistocene age. Although Dibblee (1985) stated that the Lockhart fault is not Holocene active, geomorphic evidence suggesting latest Pleistocene and, possibly, Holocene right-lateral strike-slip and oblique-slip displacement was observed by this writer near locality 27, based on air photo interpretation and field observations (Figure 3b). The majority of the Lockhart fault is moderately to poorly defined and does not have geomorphic evidence of latest Pleistocene to Holocene displacement.

The North Lockhart fault mapped by Dibblee (1968) offsets mid to late Pleistocene alluvium and is delineated by a dissected north-facing scarp that is only moderately defined in detail (locality 9, Figure 3b). To the east the North Lockhart fault is concealed by Holocene alluvium and is poorly defined. Geomorphic evidence of latest Pleistocene to Holocene displacement was not observed along the North Lockhart fault.

The South Lockhart fault is generally poorly defined at its northern end and only moderately defined at its southern end. These segments are not delineated by geomorphic evidence of latest Pleistocene to Holocene displacement (Figures 3a, 3b). The central segment of the South Lockhart fault (from locality 30 to 31, Figure 3b) is well-defined and is delineated by geomorphic features indicating Holocene faulting, such as scarps, a trough and graben in latest Pleistocene to Holocene alluvium (Figure 3b). Discontinuous, locally well-defined segments of the South Lockhart fault extend south of locality 31 and have geomorphic evidence suggesting latest Pleistocene to Holocene right-lateral strike-slip and oblique-slip displacement, such as scarps in Pleistocene alluvium, right-laterally deflected drainages, and a closed depression (Figure 3b).

HARPER FAULT ZONE

The Harper fault zone is a major northwest-trending right-lateral strike-slip fault zone that consists of the Cuddeback, Gravel Hills, Harper Valley, Black Mountain, and Harper Lake faults (Figures 2b, 3b).

The Cuddeback fault mapped by Dibblee (1968) offsets Tertiary Barstow Formation, is moderately defined, and is delineated by geomorphic features characteristic of differential erosion rather than latest Pleistocene to Holocene faulting (Figures 2b, 3b).

The Gravel Hills fault mapped by Dibblee (1968) offsets Holocene alluvium at locality 12 (Figure 2b). However, Moyle (1970) mapped Tertiary Barstow Formation at this location, rather than Holocene alluvium. The Gravel Hills fault at locality 12 is delineated by a well-defined south-facing scarp and associated closed depression that clearly indicate Holocene displacement (Figure 3b). The faulted deposit is probably reworked Barstow Formation and the faulted geomorphic surface is latest Pleistocene to early Holocene in age. The Gravel Hills fault is moderately well-defined and has geomorphic evidence of latest Pleistocene to Holocene displacement southeast to locality 32 (Figure 3b). Southeast of locality 33 the Gravel Hills fault is poorly defined and does not have geomorphic evidence of latest Pleistocene to Holocene displacement (Figures 2b, 3b).

The Harper Valley fault mapped by Dibblee (1968) and Page and Moyle (1960) is moderately well-defined and offsets latest Pleistocene and Holocene alluvium (locality 14, Figure 2b; locality 34, Figure 3b). The fault is delineated by a moderately well-defined northeast-facing scarp and trough in latest Pleistocene alluvium and ponded alluvium. The eastern fault splay mapped by Dibblee (1968) and Page and Moyle (1960) is only moderately defined and may be an erosional feature (Figures 2b, 3b). To the southeast the Harper Valley fault is poorly defined and is concealed by Holocene alluvium (Figures 2b, 3b).

The Black Mountain fault is a complex, northwest-trending zone of moderately well-defined right-lateral strike-slip faults mapped by Dibblee (1968) and Page and Moyle (1960) (Figures 2b, 3b). Faults mapped by Dibblee (1968) were generally verified, although significant differences in detail exist (Figures 2b, 3b). Fault traces that offset Pliocene Black Mountain Basalt are well-defined and are delineated by geomorphic features indicating latest Pleistocene to Holocene right-lateral strike-slip displacement, such as linear ridges and troughs, sidehill benches, closed depressions and ponded alluvium, and right-laterally deflected drainages (Figure 3b). To the southeast, the Black Mountain fault is delineated by moderately to moderately well-defined geomorphic evidence indicating latest Pleistocene to Holocene faulting (locality 37, Figure 3b).

The Harper Lake fault, a southeastern extension of the Black Mountain fault, is a moderately to poorly defined fault that, along its northern extent, is delineated by subtle scarps (or breaks-in-slope) in latest Pleistocene to Holocene alluvial fans and right-laterally deflected drainages (locality 38, Figure 3c). These geomorphic features suggest recent faulting, but are not well-defined nor are associated with additional geomorphic evidence of recent faulting. Southeast of locality 39, the Harper Lake fault is not well-defined and geomorphic features in bedrock are more characteristic of differential erosion (Figure 3c).

BLACKWATER FAULT ZONE

The Blackwater fault zone is a major, northwest-trending right-lateral strike-slip fault zone mapped by Dibblee (1968) and Moyle (1970) (Figures 2b, 3b). The Blackwater fault zone in the study area is a complex fault zone that, south of the Murphy's Well area, splays into a broad zone of generally poorly defined northwest-trending faults (i.e. the Coolgardie and Coon Canyon faults) that do not have geomorphic evidence of latest Pleistocene to Holocene offset (Figures 2b, 3b). The Fossil Canyon fault locally is moderately well-defined and offsets Pleistocene alluvium (Figure 3b).

Northwest of the Murphy's Well area the Blackwater fault is moderately well to well-defined and is delineated by geomorphic features indicating latest Pleistocene to Holocene right-lateral strke-slip displacement, such as right-laterally deflected drainages, scarps, sidehill benches, closed depressions, and ponded alluvium (localities 40, 41, Figure 3b). Contrary to what Bull (1978) reported, geomorphic features are relatively fresh along the Blackwater fault within the Black Mountain Basalt and indicate latest Pleistocene to Holocene activity.

Northeast of sec. 31, T31S, R45E the Blackwater fault is moderately defined by geomorphic features in bedrock (Figure 3b). However, a closed depression and a vague tonal lineament in Holocene alluvium suggest Holocene activity (locality 42, Figure 3b).

MT. GENERAL FAULT

The Mt. General fault, informally named in this FER, is a northwest-trending right-lateral strike-slip fault mapped by Dibblee (1960a) and Page and Moyle (1960) (Figures 2b, 3c). The Mt. General fault was generally verified as mapped by Dibblee (1968) northwest of the Mojave River, although significant differences in detail exist (Figures 2b, 3c). Southeast of the Mojave River the Mt. General fault is poorly defined and traces mapped by Dibblee (1960a) and Page and Moyle (1960) were not verified (Figure 2b).

The Mt. General fault is delineated by moderately well-defined geomorphic features indicating latest Pleistocene to Holocene right-lateral strike-slip faulting, such as right-laterally deflected drainages, scarps in late Pleistocene to Holocene alluvial fans, and tonal lineaments in Holocene alluvium (localities 43-45, Figure 3c). Northwest of Mt. General the fault can only be inferred in Holocene alluvium, based on vague tonal lineaments (Figure 3c).

FAULT ALONG WEST SIDE OF HARPER LAKE

A previously unmapped, northwest-trending fault along the west side of Harper Lake is inferred based on aligned tonal lineaments, a subtle scarp in Holocene alluvium, and the linear western shoreline of Harper Lake (Figure 3b). This inferred fault is moderately well-defined. Water well information is not sufficient to demonstrate whether or not this surface feature is associated with a ground water barrier. The scarps in alluvium conceivably could be due to shoreline processes of Harper Lake, but the alignment with moderately well-defined tonal lineaments over a length of 11 km indicates that latest Pleistocene to Holocene faulting is a reasonable explanation for these features.

RECOMMENDATIONS

Recommendations for zoning faults for special studies are based on the criteria of "sufficiently active" and "well-defined" (Hart, 1985).

LOCKHART FAULT ZONE

Zone for special studies well-defined traces of the Lockhart and South Lockhart faults shown on Figure 3b (highlighted in yellow). Do not zone the North Lockhart fault. Principal references cited should be Dibblee (1968) and Bryant (this report).

HARPER FAULT ZONE

Zone for special studies traces of the Gravel Hills, Harper Valley and Black Mountain faults shown in Figure 3b (highlighted in yellow). Principal references cited should be Dibblee (1968) and Bryant (this report).

BLACKWATER FAULT ZONE

Zone for special studies traces of the Blackwater fault and Fossil Canyon fault shown on Figure 3b (highlighted in yellow). Principal references cited should be Dibblee (1968) and Bryant (this report).

Do not zone traces of the Coolgardie, Coon Canyon and other faults of the Blackwater fault zone southeast of the Murphy's Well area. These faults are neither sufficiently active nor well-defined.

MT. GENERAL FAULT

Zone for special traces of the Mt. General fault shown on Figure 3c (highlighted in yellow). Principal reference cited should be Bryant (this report).

FAULT WEST OF HARPER LAKE

Zone for special studies traces of the fault west of Harper Lake shown in Figure 3b (highlighted in yellow). Principal reference cited should be Bryant (this report).

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Report reviewed; I concur with the recommendations.
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8/4/87

REFERENCES

Bird, P., and Rosenstock, R.W., 1984, Kinematics of present crust and mantle flow in southern California: Geological Society of America Bulletin, v.95, p. 946-957.

Bortugno, E.J., and Spittler, T.E., 1986, Geologic map of the San Bernardino quadrangle: Division of Mines and Geology Regional Geologic Map Series No. 3, Scale 1:250,000.

Bull, W.B., 1978, Tectonic geomorphology of the Mojave Desert: unpublished technical report for the U.S. Geological Survey Earthquake Hazard Reduction Program, Contract No. 14-08-001-G-394, p. 176.

Burke, D.B., Hillhouse, J.W., McKee, E.H., Miller, S.T., and Morton, J.L., 1982, Cenozoic rocks in the Barstow Basin area of southern California-Stratigraphic relations, radiometric ages, and paleomagnetism: U.S. Geological Survey Bulletin 1529-E, 16 p.

California Institute of Technology, 1985, Magnetic tape catalog, southern California earthquakes for the period 1932 to 1985: Seismological Laboratory, California Institute of Technology (unpublished).

Dibblee, T.W., Jr., 1958, Geologic map of the Boron quadrangle, Kern and San Bernardino Counties, California: U.S. Geological Survey Mineral Investigations Field Studies Map MF-204, scale 1:62,500.

Dibblee, T.W., Jr., 1960a, Geologic map of the Barstow quadrangle, San Bernardino County, California: U.S. Geological Survey Mineral Investigations Field Studies Map MF-233, Scale 1:62,500.

Dibblee, T.W., Jr., 1960b, Geologic map of the Hawes quadrangle, San Bernardino County, California: U.S. Geological Survey Mineral Investigations Field Studies Map MF-226, Scale 1:62,500.

Dibblee, T.W., Jr., 1967, Areal geology of the western Mojave Desert, California: U.S. Geological Survey Professional Paper 552, 153 p., 4 plates.

Dibblee, T.W., Jr., 1968, Geology of the Fremont Peak and Opal Mountain quadrangles, California: California Division of Mines and Geology Bulletin 188, 64 p., 4 plates, map scale 1:62,500.

Dibblee, T.W., Jr., 1970, Geologic map of the Daggett quadrangle, San Bernardino County, California: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-592, scale 1:62,500.

Dibblee, T.W., Jr., 1985, Analysis of potential fault and seismic hazards to proposed Superconductor Super Collider site in vicinity of Edwards Air Force Base, western Mojave Desert, California: unpublished report for University of California at Davis, 12 p., 13 figures.

Dokka, R.K., 1983, Displacements on late Cenozoic strike-slip faults of the central Mojave Desert, California: Geology, v. 11, No. 5, p. 305-308.

Garfunkel, Z., 1974, Model for the late Cenozoic tectonic history of the Mojave Desert, California and for its relation to adjacent areas: Geological Society of America Bulletin, v. 85, p. 1931-1944.

Hart, E.W., 1985, Fault-rupture hazard zones in California: Division of Mines and Geology Special Publication 42, 24 p.

Hewett, D.F., 1954, A fault map of the Mojave Desert region: California Division of Mines Bulletin 170, Chapter IV, p. 15-18.

Hsu, E.Y., and Wagner, D.L., (in preparation), Geologic map of the Trona-Kingman quadrangle: Division of Mines and Geology Regional Geologic Map Series, scale 1:250,000.

Jennings, C.W., Burnett, J.L., and Troxel, B.W., 1962, Trona Sheet: California Division of Mines and Geology Geologic Map of California, scale 1:250,000.

Moyle, Jr., W.R., 1970, Water wells in the Harper, Superior, and Cuddeback Valley areas, San Bernardino County, California: California Department of Water Resources Bulletin No. 91-19, 99 p., map scale 1:62,500.

Page, P.W., and Moyle, Jr., W.R., 1960, Data on water wells in the eastern part of the middle Mojave Valley area, San Bernardino County, California: California Department of Water Resources Bulletin No. 91-3, 223 p., 1 plate, scale 1:62,500.

Smith, G.I., 1964, Geology and volcanic petrology of the Lava Mountains, San Bernardino County, California: U.S. Geological Survey Professional Paper 457, 97 p., 2 plates, map scale 1:62,500.

U.S. Bureau of Land Management, 1978, Aerial photographs CAHD-77 6-18-19 to 23; 7-19-15 to 21; 7-20-19 to 21; 7-21-13 to 21; 7-22-21 to 30; 7-23-26 to 35; 7-24-28 to 35; 7-25-25 to 42; 7-26-24 to 37; 7-27-22 to 35; 7-28-26 to 37; 8-29-21 to 35; 8-30-26 to 32; 8-31-26 to 32; black and white, vertical, scale 1:30,000.

U.S. Department of Agriculture, 1953, Aerial photographs, AXL-22K-138 to 143; 147 to 150; 23K-56 to 68; 24K-102 to 118; 25K-53 to 71; 162 to 175; 28K-4 to 19; 119 to 123; 29K-78 to 82; 173 to 177; 30K-121 to 135; 31K-36 to 50; 33K-77 to 91; 169 to 173; 181 to 191; 34K-115 to 125; 133 to 137; 35K-29 to 36; 172 to 179; 37K-51 to 58; 145 to 153; 49K-136-138; 149 to 153; 155 to 164; 50K-196 to 201; black and white vertical, scale 1:20,000.

Wesnousky, S.G., 1986, Earthquakes, Quaternary faults, and seismic hazard in California: Journal of Geophysical Research, v. 91, No. B12, p. 12,587-12,631.